Digital Inclusion Alchemy by Internet Backpack: ICT Policy Implications of Edge Computing & Cyber-Physical Infrastructure for Education

Abstract

This paper assesses the broadband policy implications of the results of a STEM education research project bringing edge computing and cyber-physical infrastructure for broadband connectivity, trusted devices, and secure cloud and privacy and rights-protecting cognitive computing and wireless services, to underserved New York City school children at Timothy Dwight PS 33X in the South Bronx. The objective of the digital inclusion study was to determine if new innovations that include edge bandwidth management capabilities, specifically the Internet Backpack, would improve quality of services and learning experiences for students in underserved communities. The research question was whether this novel cyber-physical infrastructure would have a significant effect on science content mastery, by improving digital inclusion. Our data shows statistically significant improvement in science mastery when uninterrupted Internet connectivity is provided, allowing students to engage in both curricular and extracurricular science projects unimpeded by digital divides. This finding of improved academic performance from improved digital inclusion has several substantial policy implications. First, it is not sufficient to provide intermittent connectivity if students are to be expected to perform in online learning environments, as so many have experienced throughout the Covid-19 pandemic. Second, measures local school districts have taken, such as providing a Hotspot or lending laptops or tablets, while significant, may not be sufficient without enhanced edge computing capabilities, such as those made possible by the Internet Backpack.

Key words

Internet Access, Digital Divide, Science Content Mastery, Internet Backpack, Edge Computing

Introduction

The Federal Communications Commission [FCC] (2020) notes that Internet connectivity continues to improve across the United States and concludes that only 18 million people in the United States are without access to broadband. However, it notes serious flaws in its methods for estimating broadband deployment, that it consistently overstates service across the country, and that other studies estimate the number of people without broadband from 42 to 162 million. The agency also notes that millions of students cannot attend classes online and fall into the homework gap because they lack Internet access at home. Lack of connectivity is a problem in both rural and urban areas. For example, in Detroit, Michigan, more than one-half of students live in homes with no access to broadband (FCC, 2020). Bauer et al. (2020) find that during the Covid-19 pandemic, in Michigan schools, for students who lacked Internet access, had slow home access or cell phone only access, their overall GPA was approximately half a letter grade lower than students with fast home Internet access. Students who lack Internet access at home or depend on a cell phone for access score lower on homework completion, GPA and digital skills (Hampton et al., 2020). Lack of digital skills contributes to lower performance on standardized tests for these students. They are also less likely to plan to attend college and are less interested in STEM careers (Hampton et al., 2020).

Investment in Internet access for all students at school and at home is important. Digital inequities compound race and ethnicity based and socio-economic disadvantages, with long-term impacts on a student's future opportunities. Further, Internet use among household members may increase as students show other household members how to use the Internet. As policymakers prioritize closing the digital divide and evaluate how to effectively deploy Internet connectivity to all Americans, the Internet Backpack presents a cost-effective wireless investment, which has been demonstrated to lower barriers to access in underserved areas around the world.

The Internet Backpack Innovation

The Internet Backpack is a technology for decentralized connectivity, and a *sustainable microgrid*. Design and development of the computational wireless grid (edgeware) enabling technologies culminating in the Internet Backpack began in 2002 at Syracuse University, in Syracuse, New York. The Backpack's foldable solar power produces enough energy to recharge the battery with less than a day of sunlight, and therefore provides both sustainable energy and connectivity in parts of the world lacking access to both, or anywhere for education, emergency response and resilience. Our research indicates that the Internet Backpack has the potential to contribute to digital transformation for many of the 3.5 Billion presently excluded from the Internet (McKnight, Smith, Salas-Castro, Belli, 2019). While both 5G and new satellite systems have tremendous potential impact, they are not sufficient to sustain underserved communities in urban, rural, remote and other disadvantaged areas. The Internet Backpack provides solutions for 'Off-Grid' areas and areas with intermittent access to the Internet. With its technology, there no longer must be an 'Off-Grid' community, unless by choice. The Internet Backpack's immediate connectivity by cloud to edge design provides 11 to 20 networks and unlimited edgeware for connectivity to hundreds of devices for dozens of users. The ambient cyber-physical system of the Internet Backpack enables it to function in any part of the world. It has already been instrumental in providing resilient Internet connectivity for people worldwide.

As a technological model and cognitive system for mobile and sustainable immediate connectivity, and cloud to edge secure resource-sharing, the Internet Backpack has been deployed to strengthen educational systems at the school district level. Four years after introducing the Internet Backpack in the Democratic Republic of Congo to the Conflict Zone of North Kivu Province (in 2017), it remains in use by the Goma Volcano Observatory and the L'Ecole du Cinquantenaire, a local secondary school (McKnight et al., 2020). Based on the efficacy of the cyber-physical system, in 2018, the Internet Backpack was deployed at two secondary schools in Liberia, to initiate a pilot program involving ten schools. In 2019, deployment of the Internet Backpack on Costa Rica's Isla Caballo, one of the world's most remote locales, provided first time ever Internet connectivity for the local school and for a community with no running water and no electricity, except for their Internet Backpack's microgrid (McKnight et al., 2019). These schools have demonstrated the utility and efficacy of the Internet Backpack for use in STEM education among youth in primary and secondary schools. Similar first generation (now with upgraded edge software, that is, edgeware) Internet Backpacks are being used in three elementary schools in Brooklyn and the Bronx, New York and in Van Duyn Elementary School in Syracuse, New York (McKnight et al., 2021). In summary, the Internet Backpack is in use in approximately one dozen countries and has been subject to prior evaluative research. Results from above mentioned efforts indicate that access to Internet Backpacks can significantly accelerate digital transformation within low-income and underserved communities. We expect that our efforts with New York state elementary school children will lead to development of a unique socio-technical model capable of reducing digital divide through the access of cyber world. Data from the New York schools shows our approach with the backpack, Fig. 1, can be expanded to local underserved communities and eventually at a national level.

Fig. 1. Internet Backpack for Edge Connectivity
(Source: Courtesy Imcon International Inc. Used with permission)

Research Methodology

In 2019, as compared with 2015, national science test scores revealed a decrease in average scores at grade 4, with approximately 30% of 4th graders scoring below the basic level in 2019. As compared to 2015, 4th graders also scored lower in life science and earth and space sciences content areas. Further, approximately one-third to one-half of students in grades 4, 8 and 12 rarely engaged in scientific inquiry-related classroom activities (National Assessment of Educational Progress, 2019). In addition to mastering science content, it is important for students to also acquire advanced transferable reasoning skills in order to develop general scientific reasoning (National Science Teachers Association, 2015). To be globally competitive in the 21st century, the United States must improve its academic performance in science and math and close equity and access gaps.

In our study, we have used the Black Rhino of Mkomazi National Park Simulation Game as a tool for enhancing student science learning. The Mkomazi National Park Virtual Game, Saving the Black Rhino, is an immersive learning simulation that is designed to help students develop deep understanding of socio-scientific inquiry and fundamental ecological concepts. The simulation was designed by instructional technologists at One Planet Education Network (OPEN) (2020). The OPEN curriculum deploys the Internet Backpack to support STEM + (STEM Plus Humanities and Arts) transdisciplinary program series and other advanced education technologies. Additional support services for the STEM + curricula include an Internet Sensor (IoT) STEM class and field lab application hardware, software, networks, and data analytics, and related GIS Digital Mapping applications.

In Saving the Black Rhino game, students are immersed in a complex virtual learning environment, and are engaged in writing persuasive in-game reports, solving complex socio-scientific problems and creating digital and physical learning artifacts that are used to assess knowledge transfer. The Mkomazi curriculum assesses students' science content mastery, and domain specific and domain general knowledge-cognitive transfer using a multi-level assessment approach. This educational simulation is a 3D replica of the real-life Mkomazi National Park, located in Northeast Tanzania, Africa. In this game, students play the role of conservationists who are on a quest to learn how to save the critically endangered black rhino and other animal species in Tanzania. Using their new-found knowledge of local East African cultures and their research on the tactics of poachers who kill rhinos for their valuable horns, students learn about the issues threatening the survival of the black rhino and try to find feasible solutions for their survival. While exploring this 3D game environment, students experience life in the bush where the rhinos hide and learn of the work of conservationists working against time and global black-market syndicates that continue to threaten remaining East African black rhinos.

Students worked with the reserve staff to determine the number of rhinos, zebras, giraffes, and elephants the reserve can sustain, and appropriate habitats for each animal. Students then engaged in negotiations regarding the allocation of government funds to improve a local economy that was damaged when prime farming and grazing lands were converted for use as the animal reserve. Students considered the far-reaching consequences of their decisions as they began to understand how funding one opportunity rather than an alternative can impact the sustainability of both human and animal local populations. Throughout the four-month period of the quest, students actively engaged with in-game activities and wrote in-game reports. These activities and reports were characterized as immediate-level assessment and close-level activity, respectively. Science content mastery was assessed using pre/post curriculum-oriented tests that were embedded in the game environment proximal-level assessment.

Participants and Study Design

Seven non-special education fifth-grade classes participated in this study. Students were randomly placed in these classes. The study sample consisted of 74 males and 91 females. Three of the classes were the control group and the other four were the treatment group. The control group consisted of 36 males and 39 females. The treatment group consisted of 38 males and 52 females. The total study sample of 165 students was proportionate to the school's total student population of 1053 (533 males and 520 females). All fifth-grade students who participated in this study had a regular classroom teacher who was responsible for teaching all the core contents (English Language Arts, Math, and Social Studies). The primary researcher for this aspect of our work is a cluster teacher who was responsible for the science component of the core curricula.

Prior to the research study, demographic information was collected to inform data analysis and interpretation, with appropriate safeguards. We also collected Individualized Educational Plans, which ensure that elementary and secondary schoolchildren with disabilities receive appropriate specialized instruction and academic services. The fifth-grade students who participated in this study were enrolled in the researcher's general science courses. Therefore, this study used a convenience sampling method. Since the students were minors, their parents completed an Informed Consent form to allow their children to participate in the study. The majority of parents (98%) provided consent. Students whose parents did not provide consent had the same experience as those that did; however, their data were not used in the study. This study was approved by the Institutional Review Board at Pace University.

The research study employed mixed methods, involving both quantitative and qualitative data. A quantitative research design was the primary research method. Qualitative data was collected throughout all phases of the study. The researcher conducted classroom observations, which were classified as field notes. These ethnographic field notes were recorded for both the control and the treatment groups. In-game activities, quest submission reports, and game usage data were captured in back-end servers. Students' reflections and other multimedia artifacts were collected in the "Saving the Black Rhino" blog. These qualitative data were used throughout the study to assess students' understanding of socio-scientific concepts, critical thinking abilities, and content mastery. The mixed methodology was used because neither quantitative nor qualitative methods were sufficient to answer the research questions. Data were collected from students' reports, in-game activities, server data, classroom observation, field notes, and pre-test/post-tests information. The triangulation of data gathered by multiple methods further supported the rationale for mixing both quantitative and qualitative data.

Results and Analysis

The research question was, would new innovations that include edge bandwidth management capabilities, specifically the Internet Backpack, improve quality of services and learning experiences for students in underserved communities? This question focused on science content mastery. Academic content mastery was assessed using a curriculum-oriented pre and post-test that was specifically designed to assess students' mastery of socio-scientific concepts and academic content knowledge. There was statistically significant difference between the academic achievement of the treatment group compared with the control group as measured by the curriculum oriented pre/post-test.

Before the Black Rhino simulation game began, students completed a pre-game activity to assess their prior knowledge of endangered species, game reserves, and how humans affect animal habitats. The environmentalist notebook was used as a data-collecting tool prior to and during game play. Two quest submission reports were drafted in the notebook prior to submitting the final draft during game play (see Figs. 2 and 3 for pre-game and in-game activities). These qualitative data showed a positive impact on students’ science content mastery.

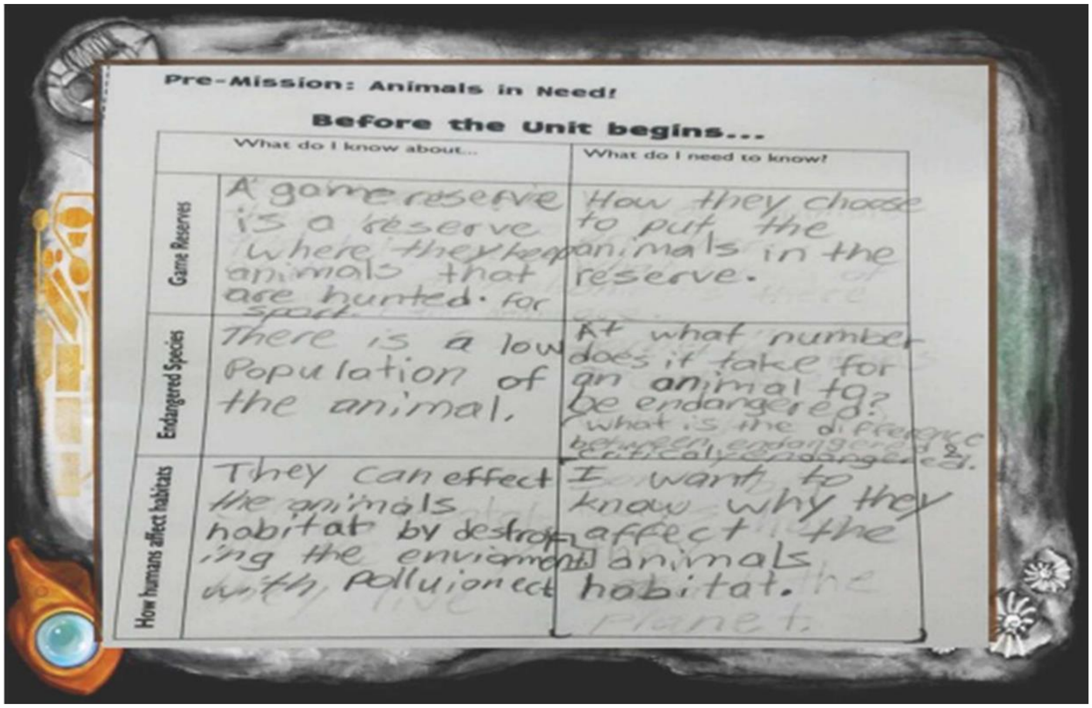

Fig. 2 Pre-mission textual data example

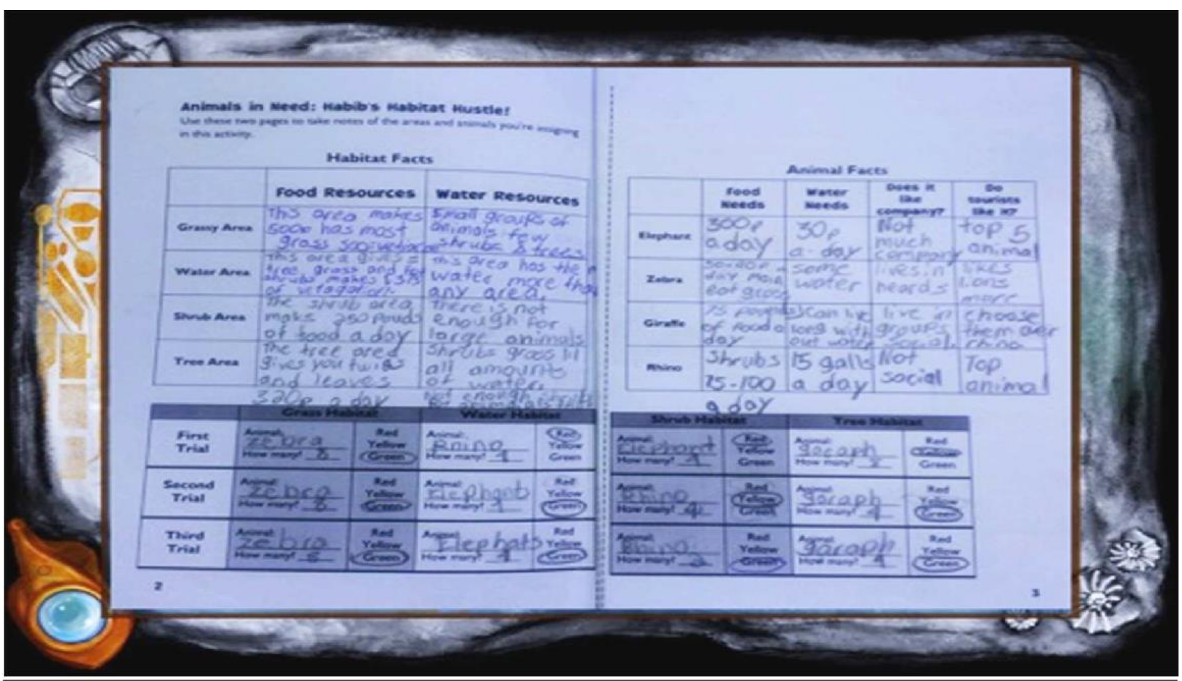

Fig. 3 Pre-mission quantitative data example

During the pre-mission, students studied the social and physical needs of four animal species: rhinos, giraffes, zebra and elephants. They also examined the characteristics of four habitats: water, shrub, grassy and tree. They recorded all data in an environmental notebook (see Fig. 3). Students used the data to solve complex logical puzzles which involved determining how many of each animal to place in the Mkomazi game reserve and into which habitat to place them. Students proceeded to the next mission after they had successfully solved these complex problems.

Table 1
Results of MKomazi Academic Achievement Pre-test and Post-test: Levene's Test for the Equality of Variances

	Equality of Variances	
Achievement	*F*	Sig.
Pretest	5.521	0.020
Posttest	11.32	0.001

The *t*-test for Equality of Means revealed a statistically significant difference between the groups for the pre and post-tests. The Equality of the Means of pre-test scores between the treatment and control groups had a *t*-value of 2.961 with a significance (2-tailed) of .004, whereas *t*-value of 10.38 with a significance (2-tailed) of .000 for the post-test scores was found, as depicted in Table 1.

Table 2
MKomazi Academic Achievement Pre-test and Post-test Independent Sample T-Test

	Pretest		Posttest	
		Equality of Variance		
	Assumed	Not Assumed	Assumed	Not Assumed
t	2.878	2.961	10.06	10.38
df	163.0	160.0	163.0	160.0
Sig. two-tailed	0.005	0.004	0.000	0.000
Mean.Diff	1.207	1.207	4.631	4.631
Std. Error Mean	0.419	0.408	0.460	0.446
95 % CI				
Lower	0.379	0.402	3.722	3.750
Upper	2.035	2.042	5.540	5.513

Note. *N* = 165. CI = confidence interval

Given the significance among means, we can conclude that the corresponding population means differ. Therefore, the results support the conclusion that there is a significant difference between the science content mastery of the treatment group compared with the control group, as measured by achievement test scores. As such, the treatment intervention is statistically confirmed to be an effective means of increasing students' mastery of science content than traditional classroom teaching, and of increasing connectivity.

The scatterplot shown in Fig. 4 depicts the significance of these results. The scatterplot can be used to interpret the data for the particular levels of the covariate because the slopes were heterogeneous. The regression line can be used to extrapolate the estimated group mean on the dependent variable for the three levels of the covariate. For example, for the medium (6.22) level, the estimated means are 10.8 and 6.97 for the treatment and control group, respectively. In this case, the mean difference between the treatment and control group is significant. The mean difference is also significant for the low and high level of the covariate. Pairwise differences among the groups also show significant differences.

The simple main effect tests were statistically significant at all three levels on the covariate (see Fig. 4). This statistical procedure was carried out to access mean differences between the groups on the dependent variable for particular levels of the covariate. As shown previously, the simple main effect tests were significant for the low level on the covariate, (1, 161) = 81.84, $p = < .001$, partial of .34, for the medium level of the covariate, (1, 161) = 88.75, $p = < .001$, partial of .36, and for the high level of the covariate, (1, 161) = 16.57, $p = < .001$, partial of .09. These findings suggest that the treatment intervention is a more effective means of helping students' mastery of science content than the traditional use of textbooks.

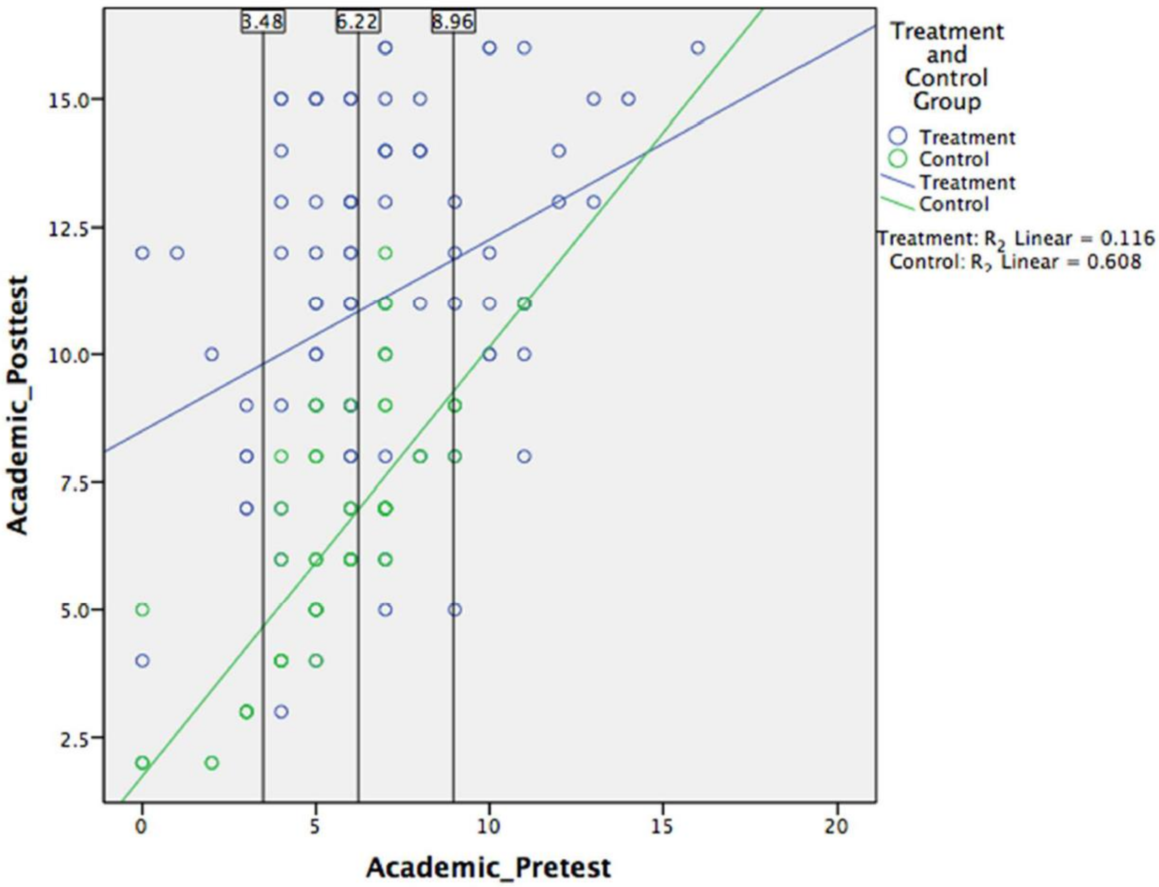

Fig. 4. Scatterplot showing the differences for the three levels of the covariate

These results also suggest that educational simulations are effective means of designing inquiry-based learning environments to help students develop science content mastery. Educational simulations are pedagogical tools which instructional designers can use to create immersive learning environments specifically designed to help students understand abstract science concepts, ideas, and fundamental scientific principles. This approach to learning is less feasible if students do not have access to the Internet. The Internet Backpack is useful in providing this access to the cyber world, both from classrooms and homes, and potentially, anywhere in between.

Summary

This study examined students' ability to apply science content knowledge which they constructed during game play to solve domain specific real-world problems and domain general critical thinking problems. Our research findings suggest that virtual simulations can be used as innovative approaches to help learners develop science content mastery and to deepen their scientific understandings. These findings bring forth the important societal question 'how can broadband accessibility be available to underserved communities, to strengthen their human capacity and future workforce productivity?'

Based on our research results, we suggest regulators utilize the Internet Backpack to develop gap-filling last few hundred feet road maps of where broadband connectivity is lacking and hence impeding school children's academic performance and opportunities to explore STEM learning topics, inside schools and at home. Results also indicate that our research output can guide future buildouts of broadband Internet and cyber-physical infrastructure. Larger-scale studies, if replicating these results, could guide educators and federal and state policymakers towards utilizing cognitive, cyber-physical systems such as the Internet Backpacks, and Science/IoT curricula, for efficient cloud to edge connectivity and innovative educational content delivery. Based on these successful results in improving student learning with edge bandwidth management for enhanced connectivity quality of service, we anticipate that the results can motivate further action by all stakeholders for the broadband underserved wherever they may be. We conclude that changing the equation for greater digital inclusion in both urban and rural resource-constrained communities with edge bandwidth management may seem like alchemy, however, it should be data-driven digital inclusion policy.

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